(Almost) Everything You Wanted to Know About a Ventilator

3

NIV is no longer delivered exclusively by the so-called “home” ventilators, but by a broad selection of machines ranging from sophisticated and expensive intensive care ventilators to those used for home care. For this reason we have divided the ventilators into broad categories, taking into account that the severity of the patient’s condition, the acuteness of the respiratory failure, and the timing and setting in which the NIV is used also determine the choice of ventilator, the interface, and disposables. Furthermore, it should be appreciated that, given the continuous technological improvements, many ventilator models are modified or even replaced within just a few months.

The first ventilators for NIV used a method of volume-controlled ventilation or synchronized intermittent mandatory ventilation (SIMV), while only some of them also offered the option of pressure-controlled ventilation. These machines did their work very well for about 30 years, ventilating thousands of patients at home, mostly in an invasive manner but also, in some cases, non invasively; however, the main limitation to the use of these ventilators in a non invasive manner was their fixed pattern of delivering the inspired gas, making them incapable of compensating for the inevitable air losses, as well as the fact that an extrinsic PEEP (PEEPe) value could not be set for some of them.

The “generational change” that gave rise to the modern pressure ventilators derived from a continuous positive airway pressure (CPAP) ventilator used for the treatment of nocturnal apnea, to which a magnetic valve was applied so that two different levels of pressure could be delivered during inspiration and expiration. This gave rise to the name “*bilevel positive airway* pressure.” The success of this ventilator, and other similar models that quickly entered the market, lay in its reduced weight and bulk, its easy portability, simplicity of use, and in the possibility of eliminating the alarms, which are often not necessary in patients who are not dependent on the ventilator.

The technological progress made in the last 20 years has meant that there is now a range of ventilators on the market which have been specifically designed for NIV and whose performance does not differ greatly from that of the ventilators for intensive care. This large variety of ventilators now available on the market does

S. Nava and F. Fanfulla, *Non Invasive Artificial Ventilation*,
DOI: 10.1007/978-88-470-5526-1_3, © Springer-Verlag Italia 2014

not always make it easy to classify them within precise classes since many of them, as indicated above, are “hybrid” models. Having said this, for the sake of simplicity we have divided the ventilators into four main classes:

- Intensive care ventilators with an NIV module;
- Intensive care ventilators specific for NIV;
- Simple and/or home bilevel ventilators;
- Stand-alone CPAP.

3.1 How a Ventilator Works

Here below we try to simplify some of the basic concepts regarding how a ventilator works, which are often misunderstood by the “general public”.

The task of a ventilator is to transform energy into one of the output variables, such as flow, pressure, or volume. This can be achieved by applying a positive pressure to the airways or a subatmospheric pressure to the exterior of the chest, as in the case of negative pressure ventilation.

Schematically a ventilator can be classified as pressure, volume, flow, and time controlled. From a practical point of view it is useful to keep the following rules in mind:

- if the pressure signal is not altered when the mechanical properties of the patient change, the ventilator is *pressure* controlled;
- if the volume delivered is measured directly by the ventilator, then the ventilator is *volume* controlled;
- if the volume delivered is determined by a flow transducer, the ventilator is *flow*-cycled;
- if the flow and volume signals are altered following changes in resistances and compliance, the ventilator is *time*-controlled.

The most commonly used ventilators are, of course, those cycled by volume or pressure. Ventilators require a source of electricity, which may be an alternating current (AC), or direct current (DC) when battery-powered.

3.1.1 Pressurized Gas System

The source of gas may be an external gas at high pressure, as in the case of a centralized delivery system, an internal compressor, turbine or a piston, or a hybrid system.

Simplifying the matter, a ventilator with a NIV option can work with oxygen and air at high pressure (i.e., 4 atmospheres) or oxygen and air at atmospheric pressure.

In the former category of machine, typically present in Intensive Care Units, the pressure within the ventilator is reduced to atmospheric level in order to allow the patient to breathe physiologically. The peak flow delivered is usually very fast, reaching >200 L/m and the flow is maintained constant at a level of 130–150 L/m.

In the latter category of ventilator, to which most of the ventilators designed specifically for NIV belong, the piston or a turbine aspirates air from the atmosphere. The simultaneous use of oxygen at a high flow rate means that these machines can also be useful in the Intensive Care Unit. The peak flow exceeds 200 L/m considerably, but, particularly in the oldest ventilators, the application of resistance can lead to a dramatic reduction in flow to values even below <100 L/m. Fast turbines or turbines that rotate at a constant velocity regulated by a proportional valve have enabled the latest generation ventilators to perform equally well as those fed with oxygen and air at high pressure. These machines can very often meet the ventilatory requirements of patients in respiratory distress.

Some turbine-based home ventilators have the option of being able to enrich the system only with oxygen at a low flow (from a cylinder or the classical hospital flow meter), but in this case the pressure of the gas is not constant.

3.1.2 Source of Gas

The ventilators in both categories very frequently include an internal blender guided by a proportional valve. Some ventilators that work with room air do not have a real and proper blender, but an oxygen-delivering system consisting of a proportional valve that combines the air sucked in by the turbine.

3.1.3 Inspiratory and Expiratory Valves

The main task of the two valves is to regulate the respiratory cycle and in particular to control the beginning and the end of the inspiratory phase. In most ventilators the inspiratory valve is regulated by an on–off system, or by a proportional valve (typically solenoid) which opens and closes in proportion to the flow, potentially keeping the circuit open all the time.

The expiratory valve can, therefore, work with an open-close mechanism, in alternation with the inspiratory valve (a typical “mushroom” o “diaphragm” valve), or with proportional opening, as described above. The expiratory valves also determine the pressure of the system during the expiratory phase, at atmospheric level or maintaining a positive expiratory pressure (external PEEP).

Solenoid valves or microprocessors that regulate the expiratory valve are useful in order to reduce the expiratory time constants, particularly in patients with limited flow. In some ventilators and modalities the so-called expiratory valves can be kept active at all times: this enables the patient to breathe spontaneously during a pressure-controlled breath (i.e., APRV or BiPAP).

3.1.4 Inspiratory and Expiratory Triggers

The reader is referred to the chapters on ventilator settings.

3.1.5 Alarms

Almost all ventilators have "absolute" safety alarms that cannot be deactivated by the operator, since their silencing could put the patient's health at risk. The alarms in this category are those related to failure of the electrical current, apnea, FiO_2, and high pressure, this last usually being placed between the inspiratory and expiratory valve and acting automatically to eliminate any excess pressure in the ventilator circuit. An interesting option of some ventilators with a NIV mode is the differentiation of the alarm for real disconnection from that of massive air loss because of poor positioning of the interface. The most common alarms that the operator can modify are those related to the pressure, volume, frequency, and ventilation/minute.

3.1.6 The Monitoring System

The presence or absence of a monitoring system does not directly affect the patient's safety, but it certainly helps the operator to interpret the patient's clinical course better.

During NIV, it is definitely important to be able to see the values of the tidal volume, which we remind you, are calculated as the integral of the flow signal. The expiratory volume is essential in order to control the efficacy of the mechanical ventilation. The difference between the inspired volume and the expired volume is useful for quantifying the presence of losses of the system during NIV. There are ventilators that measure the two volumes (i.e., inspiratory and expiratory) directly and others that extrapolate them from the flow signal and from the losses. The true measure of the two volumes can only be obtained with two pneumotachographs placed on the inspiratory and expiratory limbs, or with one pneumotachograph introduced at the *Y* of a double-tube system. The technical data sheet of each ventilator includes information on the ventilator's monitoring system.

Fortunately, ventilators that determined the volume exclusively from the inspiratory flow, without taking into consideration any losses, have almost completely disappeared from the market. Indeed, in this case the ventilator algorithm tried to compensate by increasing the inspiratory flow, thereby directly influencing the reading of the volume, which became abnormally higher the greater the losses were. We found numbers which indicated volumes even greater than a liter, when perhaps the real tidal volume was only a few tens of milliliters. For many years this led to confusion.

Although pressure-preset NIV is able to compensate for nonintentional leaks better than volume-preset NIV, a constant tidal volume may not be guaranteed in the presence of changes in respiratory impedance. To overcome this problem, a volume-guaranteed (VTG) mode has recently been introduced in most bilevel ventilators both in double-limb and in single-limb circuits. The ability of the VTG mode to compensate for nonintentional leaks depends however strictly on whether a “vented” (i.e., nonrebreathing valve) or “non-vented” (true expiratory valves) circuit configuration is used. This difference must be taken into account as a possible risk when a VTG mode is used with a “non-vented” circuit (see also in the next chapter for further details).

Flow, pressure, and volume traces have become very popular in recent years; in our opinion their real value is directly proportional to the pathophysiological knowledge of the operator. These curves are very useful for visualizing the patient-ventilator interaction and the characteristics of the expiratory flow. In the invasively ventilated patient, in whom deep sedation and/or neuromuscular blockade is possible, the values of the mechanical respiration can be measured directly (for example, compliance, resistance, static intrinsic PEEP) through occlusion maneuvers at end inspiration and expiration.

3.1.7 Comparative Studies

We don’t want to be part of the ‘politically correct’ and, therefore, often hypocritical herd and state here that, although there have been giant steps forward in technology and almost all the available ventilators are reliable and safe, there are important differences between ventilators in the same category. First of all we want to belie the common belief that critical care ventilators are necessarily more sophisticated and “perform better” only because they cost more and have more elaborate monitoring. We should remember that a ventilator for NIV must, by principle, have complex algorithms to compensate for losses. This said, various studies have now been published comparing the performance of a variety of machines *in vitro*, although almost never *in vivo*. We invite the reader to analyze the studies cited at the end of this chapter to discover the reliability of inspiratory and expiratory triggering systems, the effort required by the patients and last, but not least, the ease of use. In this regards, we want to report the findings of Gonzalez-Bermejo (Gonzalez-Bermejo et al. 2006), who demonstrated that, for the same operator, the time needed to start a ventilator varies between 20 and 120 s depending on the type of machine used. You should also remember that the presence of losses significantly influences the performance of a ventilator.

Furthermore, if and when you read published studies, you should appreciate that: (1) they are often already “old” when they are published, since the algorithms in some of the ventilators could have been changed or the ventilators have been replaced by new models; (2) extrapolation of *in vitro* findings to patients may not be appropriate; and (3) the tests carried out to verify the efficacy of the compensation of losses are often performed with predetermined values (usually moderate and severe losses) whereas in real life the air that escapes can vary considerably from breath to breath.

Finally, remember that the performance of a ventilator should not be judged from reports or brochures that companies show you. For example, the flow supplied by a ventilator is not necessarily synonymous with good or poor performance; a machine can guarantee a high flow, but have you ever asked yourself for how many seconds that flow can be maintained varying, for example, the FiO_2 or the resistive component? The efficacy of a ventilator is also judged on the basis of this.

Suggested Reading

Carlucci A, Schreiber A, Mattei A, Malovini A, Bellinati J, Ceriana P, Gregoretti C (2013) The configuration of bi-level ventilator circuits may affect compensation for non-intentional leaks during volume-targeted ventilation. Intensive Care Med 39(1):59–65

Carteaux G, Lyazidi A, Cordoba-Izquierdo A, Vignaux L, Jolliet P, Thille A, Richard JC, Brochard L (2012) Patient-ventilator asynchrony during noninvasive ventilation a bench and clinical study. Chest 142(2):367–376

Gonzalez-Bermejo J, Laplanche V, Husseini FE et al (2006) Evaluation of user-friendliness of 11 home mechanical ventilators. Eur Respir J 27(6):1236–1243

Gregoretti C, Navalesi P, Tosetti I, Pelosi P (2008) How to choose an intensive care unit ventilator? The buyers' guide to respiratory care products. Available on http://www.ersbuyersguide.org/

Kaczmarek RM et al (2006) Basic principles of ventilatory machinery. In: Tobin M (ed) Principles and practice of mechanical ventilation. McGraw-Hill, New York

Mehta S, McCool FD, Hill NS (2001) Leak compensation in positive pressure ventilators: a lung model study. Eur Respir J 17(2):259–267

Richard JC, Carlucci A, Breton L et al (2002) Bench testing of pressure support ventilation with three different generations of ventilators. Intensive Care Med 28(8):1049–1057

Vignaux L, Tassaux D, Jolliet P (2007) Performance of noninvasive ventilation modes on ICU ventilators during pressure support: a bench model study. Intensive Care Med 33(8): 1444–1451

Vitacca M, Barbano L, D'Anna S (2002) Comparison of five bilevel pressure ventilators in patients with chronic respiratory failure. A physiologic study. Chest 122(6):2105–2114